Incorporating Unit Commitment Constraints in Long-term Planning Models

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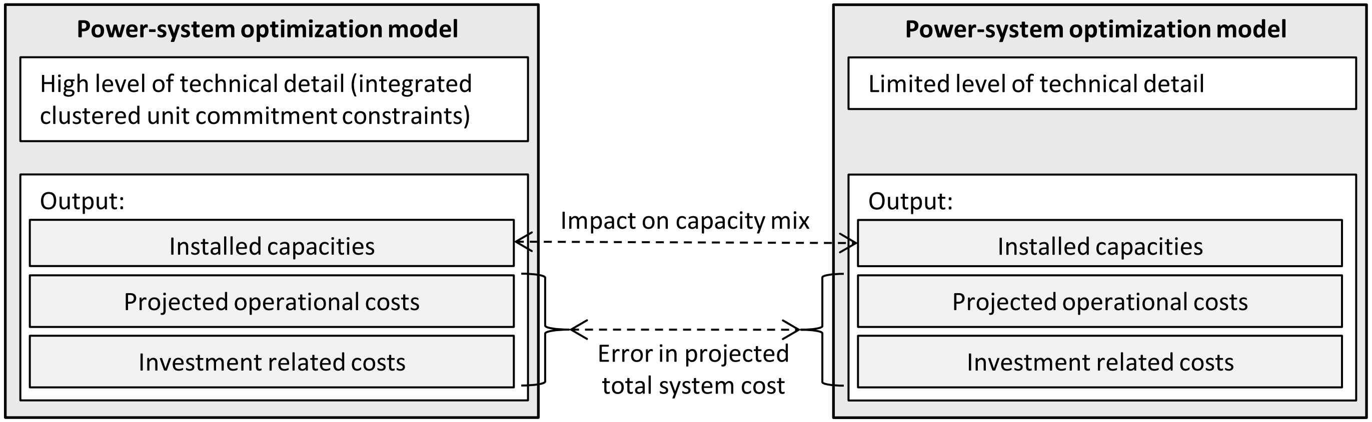
Technical representation in long-term planning models

- Technical representation:
  - Plant-level constraints: minimum operating point, ramp rates, etc.
  - System-level constraints: operating reserve requirements

- Main research questions:
  - What is the relevance of incorporating detailed technical constraints in planning models?
  - Can we represent the impact of technical constraints in a reduced formulation?
    - What is the impact of each specific constraint?

Methodology



- Limited level of technical detail:
  - No technical constraints at all: merit-order dispatch (MO)
  - Specific technical constraints not considered
  - Reduced formulation

- Reference: investment model with integrated clustered unit commitment constraints

Meus, J., Poncelet, K., and Delarue, E. Applicability of a clustered unit commitment model in power system modeling. IEEE Transactions on Power Systems PP, 99 (2017), 1–1

Methodology

- Impact technical constraints dependent on:
  - the capacity mix: 4 scenarios

Scenario	A	B	C	D
Description	low IRES, nuclear baseload	low IRES, no nuclear	high IRES, no nuclear	high IRES, nuclear baseload
$T^{GHG}[EUR/ton]$	0	0	30	100
$S^{IRES}[EUR/MWh]$	0	0	50	50
Technologies excluded	-	nuclear	-	-

  - the available flexibility:
    - 4 cases:

Case	low flex	high flex	low flex S	high flex S
Flexibility of thermal power plants	low	high	low	high
Investments in storage allowed	no	no	yes	yes

Methodology

- Technical constraints depend
  - the capacity mix:

Technical characteristic	Flexibility case	NUC	COAL SC	CCGT	OCGT
MSOP [$\%/P_{nom}$]	low flex	50	40	50	50
	high flex	40	25	30	20
Eff. loss at MSOP [%pt]	low flex	5	2	11	22
	high flex	1.8	2	3.2	9
Ramp rate [$\%P_{nom}$ /min]	low flex	0.25	0.66	0.83	0.83
	high flex	5	4	10	25
Ramp cost [EUR/ ΔMW]	low flex	0	1.71	0.53	2.02
	high flex	0	1.09	0.22	0.68
MUT [h]	low flex	24	10	6	1
	high flex	0.25	0.25	0.25	0.25
MDT [h]	low flex	24	10	6	1
	high flex	24	3	0.5	0.25
Start-up energy [$MWh_{th}/\Delta MW_e$]	low flex	46.7	3.6	1.8	0.0
	high flex	16.7	3.6	1.5	0.0
Start-up depreciation [EUR/ΔMW_e]	low flex	1.7	70.3	68.4	105.0
	high flex	1.7	45.1	24.5	19.4

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    - 4 cases:

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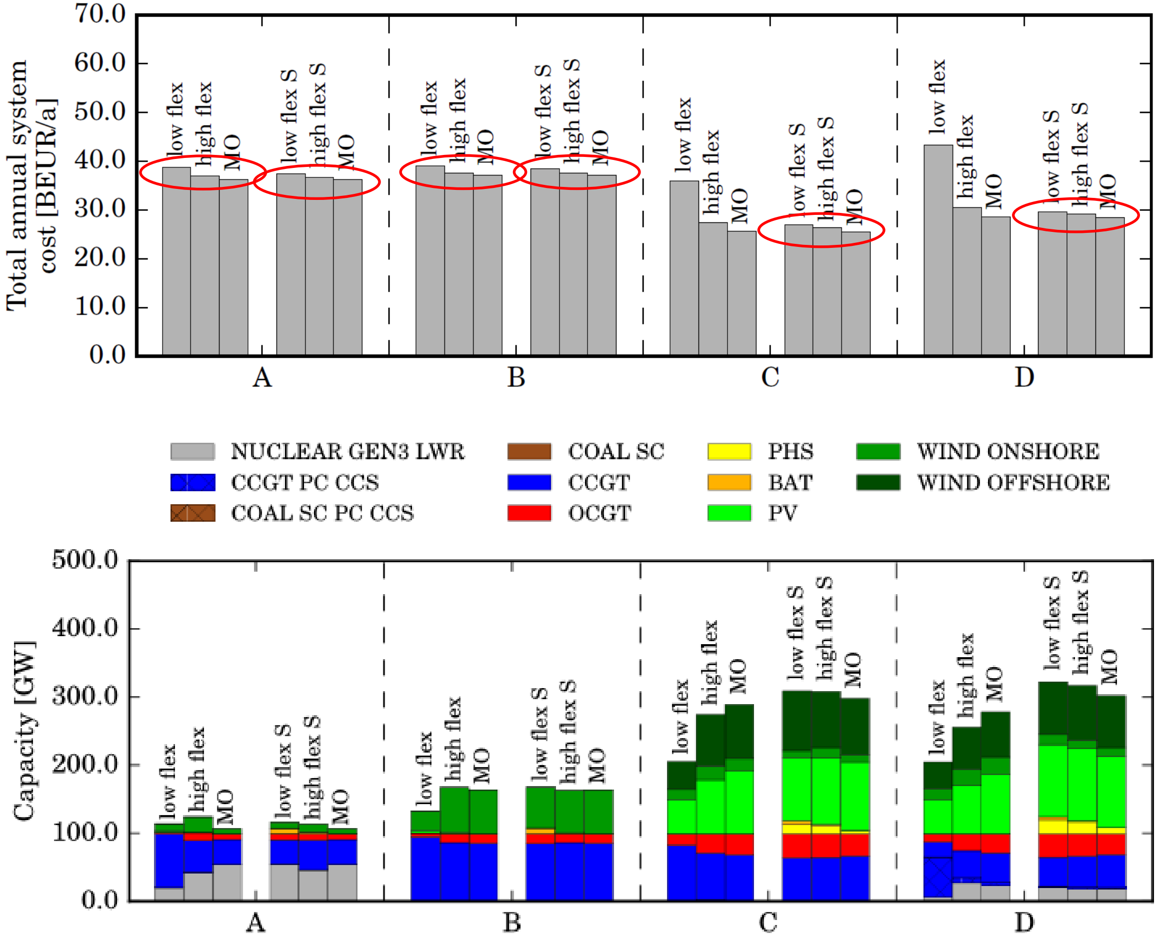
Methodology

- German system
- 8 representative weeks
- Greenfield model for 2050
- No grid constraints considered
- Reserve sizing taken from NREL's Resource Planning Model:

Reserve type	Sizing	Activation time
Frequency Regulation Reserves	1% of demand	Sub 5 minutes, 100% spin
Spinning Contingency Reserves	Maximum of 6% of demand and the largest contingency	10 minutes, 50% spin
Variable Renewable Forecast Error Reserves	10% of wind generation + 7.5% of solar generation	1 hour, 100% spin

Results: a) relevance of incorporating technical constraints in planning models



Conclusions:

- In most cases, technical constraints have a limited impact on projected system costs and capacity mix

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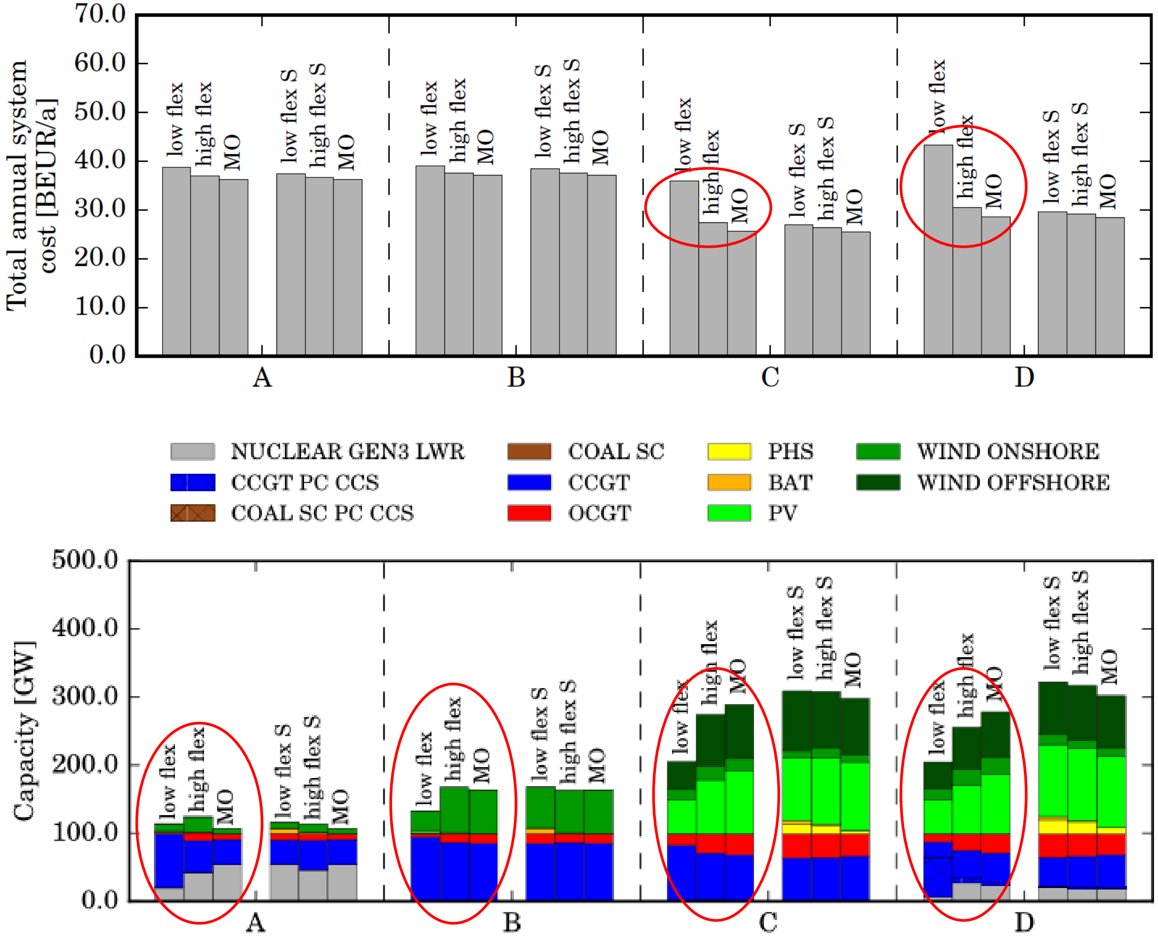
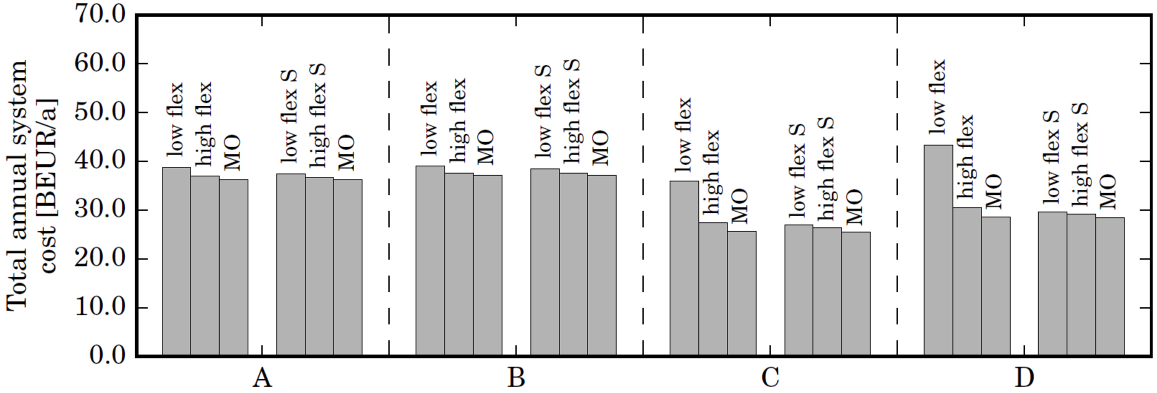


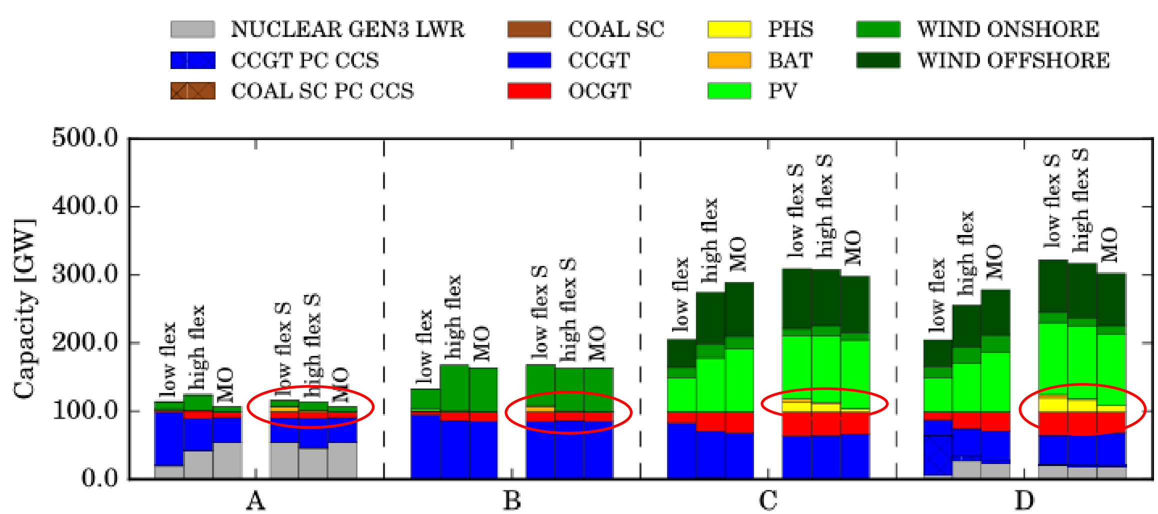
Conclusions:

- In most cases, technical constraints have a limited impact on projected system costs and capacity mix
- Exception 1: whenever no storage, inflexible power plants (and high IRES penetration)
  - Value of flexibility extremely high -> unrealistic
  - Recommendation: consider different sources of flexibility

Scenario	low flex S	low flex Sx3	low flex
C	26.9	28.6	33.4
D	29.7	31.9	43.3

Results: a) relevance of incorporating technical constraints in planning models





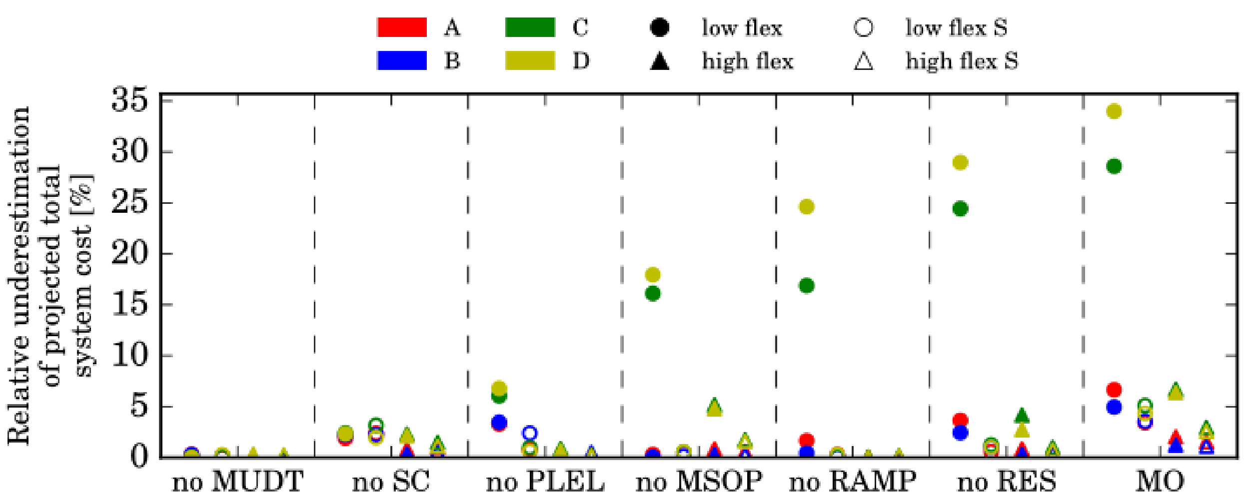
Conclusions:

- In most cases, technical constraints have a limited impact on projected system costs and capacity mix
- Exception 1: whenever no storage, inflexible power plants (and high IRES penetration)
  - Value of flexibility extremely high -> unrealistic
  - Recommendation: consider different sources of flexibility
- Exception 2: investments in storage technologies
  - Flexibility of power plants high impact, particularly on investments in batteries

Results: b) impact of neglecting specific constraints

Considered constraints:

- MUDT: minimum up and down time
- SC: start-up costs
- PLEL: part-load efficiency losses
- MSOP: minimum stable operating point
- RAMP: ramping constraints
- RES: reserve requirements



Conclusions:

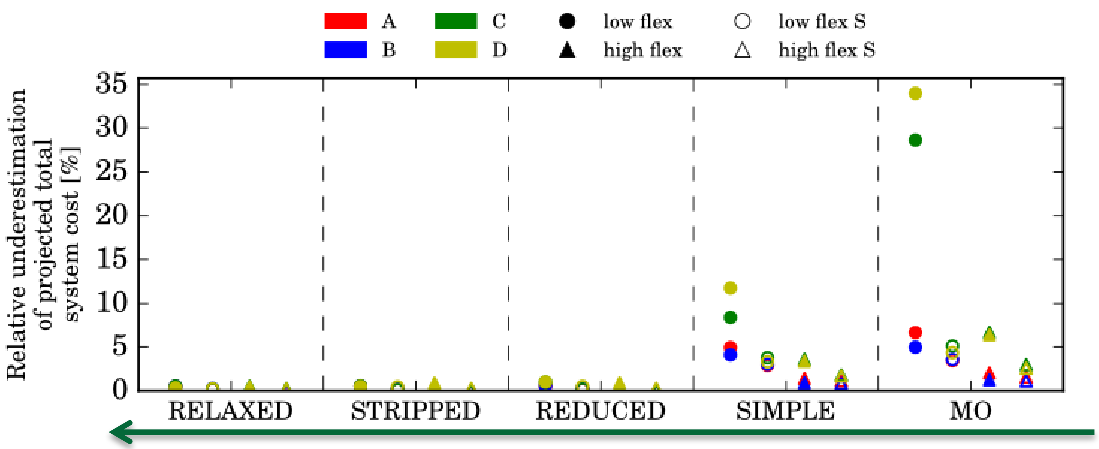
- MUDT: ~no impact
- SC: significant but limited impact across scenarios and cases
- Reserve requirements: can have a high impact on costs, but should not (but important for investments in storage):
  - Recommendation: allow other sources of flexibility to provide reserves
  - Warning: assumptions regarding sizing and activation time of reserves can have a strong impact
- Impact of ramping constraints and minimum stable operating point, and part-load efficiency losses directly related to provision of reserves
- Ramping constraints: only relevant for the provision of reserves. Hourly ramping constraints never binding

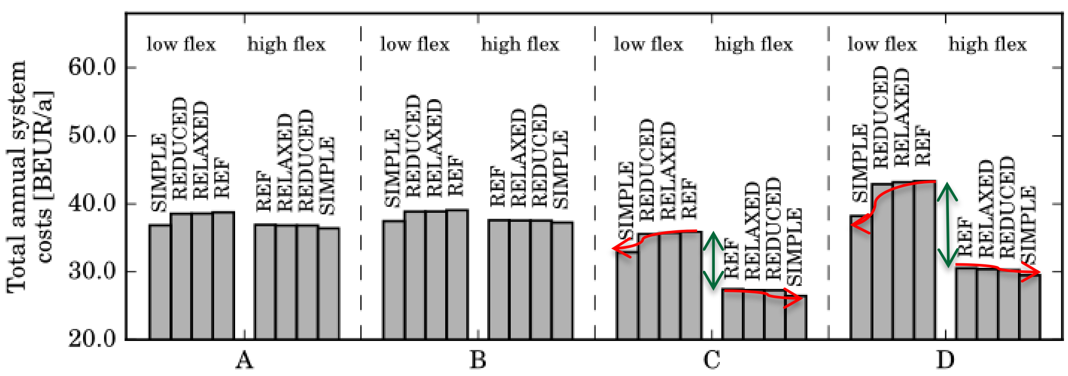
Results: c) Reduced formulation

- Consider different levels of technical detail:
  - REF: all constraints, integer commitment variables
  - RELAXED = REF + continuous commitment variables
  - STRIPPED = RELAXED + no MUDT + no hourly ramping constraints + combined reserve categories
  - REDUCED = STRIPPED + no start-up or shut-down range (drop variables ${n^{su}}_t, {n^{sd}}_t$)
  - SIMPLE = REDUCED + no commitment variables (${n^{on}}_t$) + no start-up costs
    - Optimistic estimation of ramping capability and head room based on generation level
  - MO: no technical constraints

Increasing technical detail

Results: c) Reduced formulation





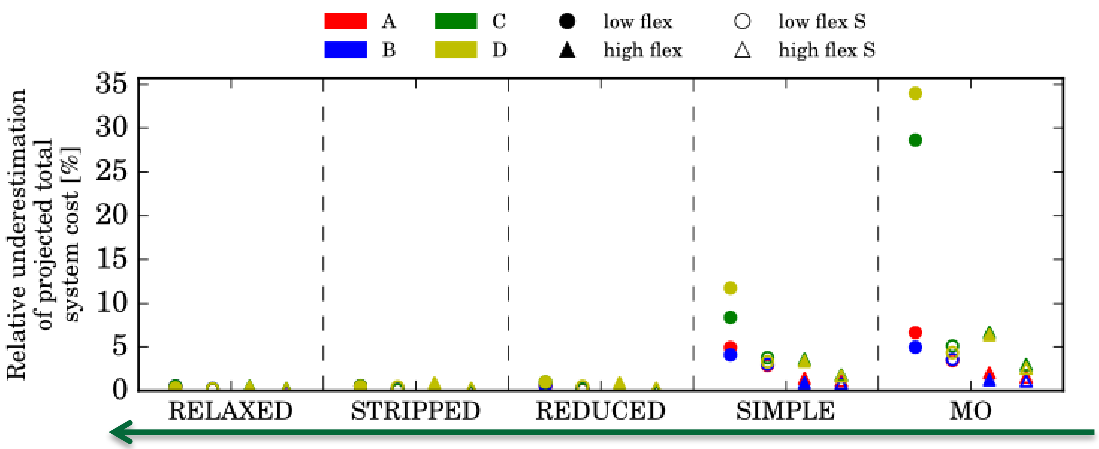
Data uncertainty

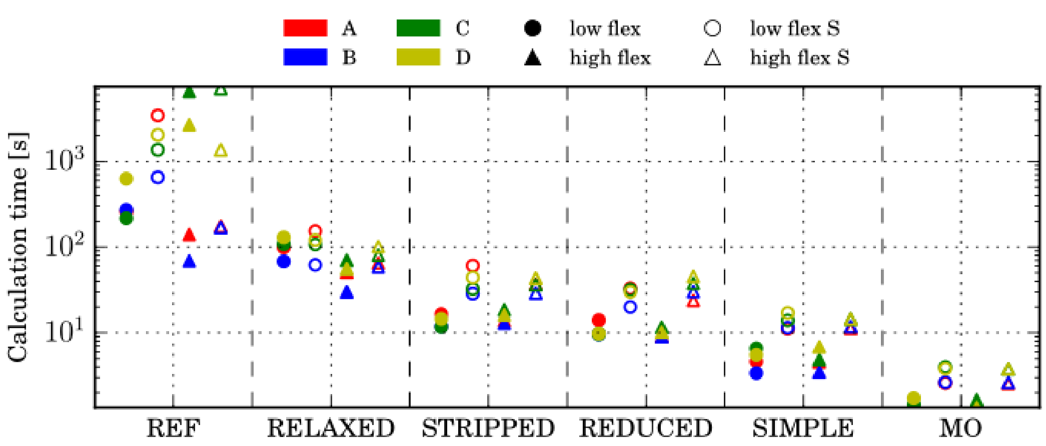
Simplified formulation

Conclusions:

- Simplified formulations can accurately approximate full UC sufficiently accurate
  - Sufficiently: given uncertainty regarding cycling characteristics
- No need for integer variables in planning models

Results: c) Reduced formulation





Conclusions:

- Simplified formulations can accurately approximate full UC sufficiently accurate
  - Sufficiently: given uncertainty regarding cycling characteristics
- No need for integer variables in planning models
- Computation time can be strongly reduced
  - But remains an order of magnitude higher than not incorporating technical constraints (REDUCED formulation)

Conclusions

- Relevancy of incorporating technical constraints in planning models:
  - Significant but small impact on cost projections
  - Small impact on capacity mix, exception storage technologies
- Simplified formulations of technical constraints
  - Capable of accurately approximating full UC problem
  - Strongly reduce computational cost
- Warnings/recommendations:
  - Other sources of flexibility must be considered when incorporating technical constraints in planning models, also for the provision of reserves
  - Strong assumptions made on reserve sizing, activation time of reserves and ability of alternative sources of flexibility to provide reserves
    - Can strongly impact results
    - More research required